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**Design and Performance Characteristics
of the
E769 Beamline Transition Radiation Detector***

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DESIGN AND PERFORMANCE CHARACTERISTICS OF THE E769 BEAMLINE TRANSITION RADIATION DETECTOR*

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Abstract

A Transition Radiation Detector (TRD) was designed and built for E769, a Fermilab Fixed Target experiment, for use in separating pions from protons or kaons in a 250 GeV/c positive beam at the Tagged Photon Laboratory (TPL). Requirements placed on the detector were that it operate in a high rate (≈ 2 MHz) environment and that it be relatively easy to build since it had to be ready approximately one year from the date of its inception. The short time available precluded exposing prototypes to a test beam making it necessary to rely on source testing and Monte Carlo programs to predict the detector performance. When operated in the beam, the detector performance was in good agreement with these predictions. For a pion detection efficiency of 87%, the contamination by protons of a sample of TRD tagged pions was 2%.

Introduction

The energy window within which pions can be separated from kaons or protons by transition radiation is rather narrow, as pointed out by Dolgoshien in a recent review article¹. The range of secondary hadron beam energies attainable at TPL overlaps this window making beam particle identification by this technique a viable choice. Two tagging elements were required in the beam for E769, since data were taken in both positive and negative beams at 250 GeV/c. A clean separation of pions from kaons or anti-protons in the negative beam, which was 91% pions, 7% kaons, and 3% anti-protons, could be achieved with a single tagging element, a Differential Isochronous Self-Focusing Cerenkov counter (DISC)², set at a pressure to give a positive tag for kaons. In the positive beam, however, where the particle mix was 59% pions, 35% protons, and 6% kaons, a second detector for particle identification was required to separate the pions from the protons and remaining kaons in the sample not identified by the DISC as kaons. It was for this purpose that the TRD was built. The beam energy was within the range of operation of both detectors, i. e., low enough to allow separation of the kaons from the pions by the DISC, which has a resolution of $\Delta\beta \geq 4 \times 10^{-7}$, and high enough to be well above the threshold for production of transition radiation by the pions. Figure 1 shows the average number of TR photons detected per module of the TRD for the three particle types as a function of energy as predicted by the Monte Carlo program³ to be described in more detail in what follows. The numbers have been multiplied by the efficiency factor of .83 measured in the source tests. Saturation has been put in by hand on these curves using the formulae in Ref.[4].

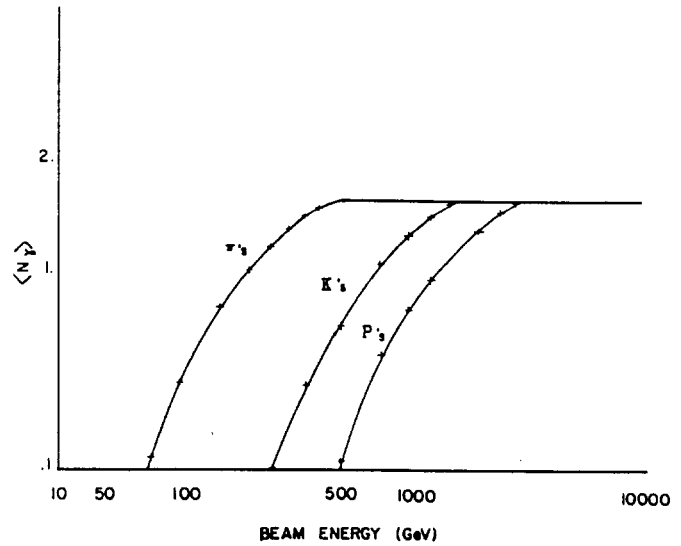


Fig 1. Average number of TR photons detected per module of the TRD for π 's, K's, and p's as a function of beam energy. The efficiency factor of .83 measured in the source tests is included.

Figure 2 shows the distribution of events from a typical positive beam run plotted along two axes, one of which is the number of TRD planes that fired and the other of which is the number of DISC phototubes that fired. The peaks due to the three incident particle species are clearly separated. To our knowledge, this is the first use of a TRD for particle identification in an incident hadron beam during data taking for a running experiment, although several authors^{5,6,7,8} have reported on the possibility of using a TRD to separate pions from kaons or protons in this energy regime based on test beam results with prototype radiators and detectors. Several times during the course of the data taking run, special data tapes were taken for which the DISC pressure was tuned to give a positive tag for protons or pions for studies of the TRD performance.

System Design

Radiator-Chamber Assemblies

A TRD had been built at the Leningrad Nuclear Physics Institute and operated successfully for E715 at Fermilab to separate electrons from pions in the 5-80 GeV range⁹, thus for values of the Lorentz factor, γ , of order 10^4 to 10^5 . It was decided to build a similar system for E769, altering the parameters as appropriate for tagging pions in a 250 GeV/c hadron beam for which $\gamma \approx 1800$. The TRD was to be modular, with each basic building block consisting of a several hundred foil radiator followed by a proportional wire chamber filled with

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a gas containing a high percentage of xenon, because it has a large absorption cross section for TR photons, which are in the x-ray region. The proportional chambers did not need to have a large active area since the transverse beam size where the TRD was to be placed was expected to have $\sigma \approx 1/3$ inch. A chamber that was 3 inches square in active area had been built and operated in a test beam at Fermilab as a prototype for the many 6 inch chambers that now operate reliably with a minimum of attention both as tracking detectors and beam profile monitors in beamlines all over the laboratory¹⁰. The design of the smaller chamber was ideal for use in a high rate environment. The wire spacing was only 1 mm. and the cell depth .635 cm. so that both the overall charge collection time and the maximum drift time (≤ 120 ns) would be short even in xenon which is a relatively slow gas. Thin aluminized mylar, 140 Å aluminum cladding on both sides of 1/2 mil mylar, was substituted for the aluminum foil windows and cathodes used for the original chamber to reduce attenuation of the TR photons.

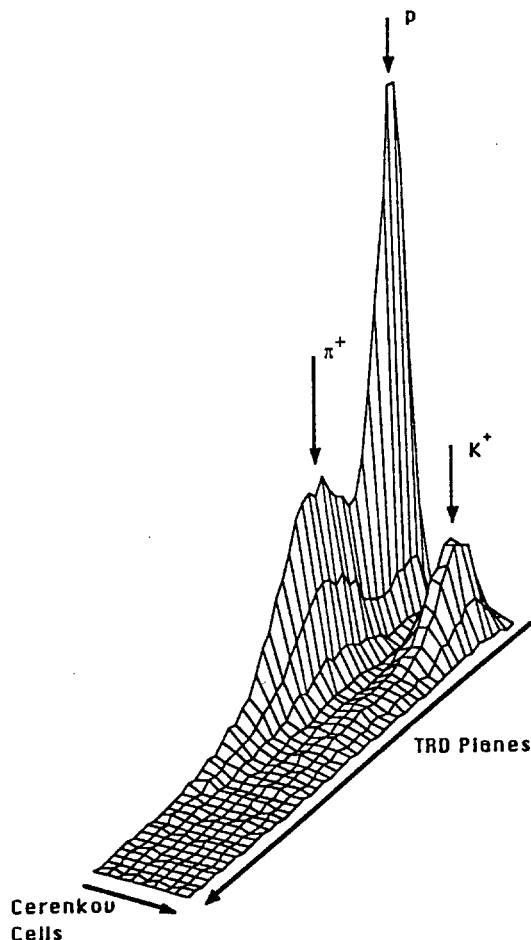


Fig 2. Distribution of events from a typical E769 positive beam data tape plotted along two axes, one of which is the number of TRD planes that fired and the other of which is the number of DISC photomultiplier tubes that fired.

The number and thickness of the radiator foils and the number of chamber gaps per assembly were decided by Monte Carlo keeping such practical considerations as the total amount of material in the beam and the expense of construction in mind. Two chamber gaps were found to be sufficient since the

mean free path in xenon for TR photons at the peak energy produced in useful radiators is short, and, in subsequent gaps the probability for capture of a TR photon would be comparable to the probability of a false signal from production of a delta-ray along the charged particle track. In choosing materials for the radiator, lithium was ruled out for a detector that was to be built on such a tight time schedule by the enormous difficulty in construction and handling. Polypropylene was available in a variety of appropriate thicknesses and seemed a good choice based on previous reports. The number of foils to be used in the radiators was limited to no more than 200 since the radiators represent the largest amount of material in the detector. Because the foils themselves absorb the lower energy photons produced, the addition of foils beyond 200 was seen not to improve the overall photon yield enough to justify the increased amount of material. Figure 3 shows the average number of TR photons as a function of energy which would be produced and detected in the two-plane xenon chamber for a 250 GeV/c π incident for 200-foil polypropylene radiators of varying thickness according to the Maryland TRD Monte Carlo program³. The gap thickness is the same for the three, 180 μ m. In the radiators fabricated for the actual detector modules, this gap was maintained by using spacers of nylon net cut out at the center to reduce the amount of material in the beam and to avoid attenuation of the TR photons. The radiator volume was flushed with helium because it has a lower plasma frequency than air making it a better gap material. This also results in a smaller amount of material in the beam than for air gaps. The integrated number of photons is much lower for the thickest foil set than for the other two because of the self-absorption of the foils. While the integral is almost the same for the other two sets, the spectra are quite different. The 12.7 μ m set seemed a better choice to use in the device because the spectrum it radiates does not rise as rapidly at low energy in the vicinity of the expected threshold cut at 4 keV, thus making the detector less susceptible to small chamber gain shifts during the run.

The 1/8 inch space between the chamber windows and the outer cathodes was filled with nitrogen to avoid the helium leaking into the chamber volume and changing the gain. The three gas volumes were held at equal pressure to keep the chamber cathodes flat and thus the gain uniform across the planes. The number of radiator-chamber assemblies used in the detector was 24. Further subdivision of the system into modules with radiators containing half as many foils followed by chambers with only a single gap would yield a somewhat larger number of photons detected. The overall improvement was not considered to be sufficient to justify the additional expense in building twice as many assemblies. Also, gas containment becomes more troublesome because of the increase in the number of interfaces between different gasses. A schematic of one module with labels showing the final design parameters detailed in this discussion is shown as Figure 4. Figure 5 is a photograph of one of the TRD modules with attached preamplifier cards. The array of modules appears in the background on the specially designed system stand.

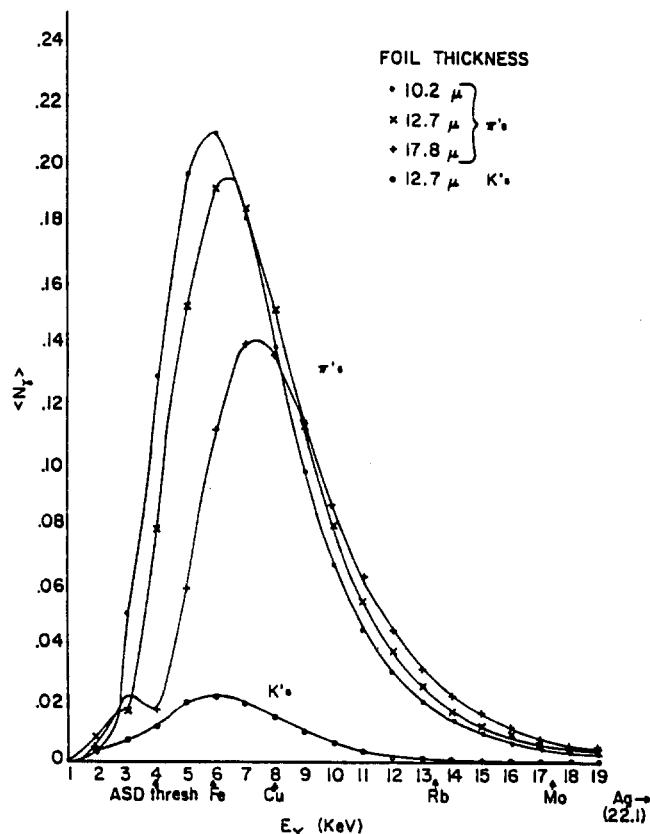


Fig 3. Average number of TR photons detected per module of the TRD for a 250 GeV/c π incident as a function of photon energy for 200 foil radiators of varying thickness.

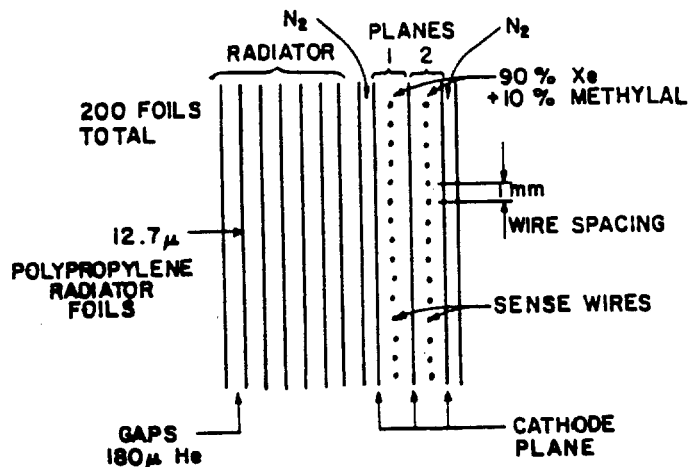


Fig 4. Schematic of a radiator-chamber module showing the final design parameters discussed in the text.

Associated Electronics

Since the method of cluster counting had been shown by previous authors^{5,11} to be a more effective means by which to electronically separate particles by type using TR than overall charge collection, it was decided to use this method of selection. This required use of fast amplifiers with integration times of order 30 ns (≈ 1 mm drift). Such circuits existed at the laboratory for use in drift chambers where multi-hit capability per wire was required, and these were suitable for this application with minor modifications.

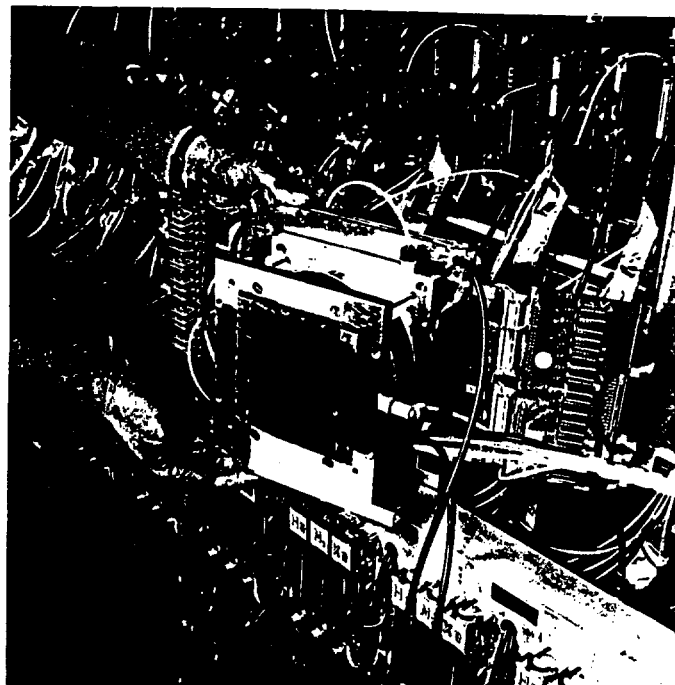


Fig 5. Photograph of one module of the TRD with attached preamplifiers. The array of modules on the system stand designed to hold them is seen in the background.

The 64 wires per plane were wire OR'd in sets of four and input to a common-base low-noise pre-amplifier designed by Radeka for high rate beam multi-wire proportional chambers.¹² The preamplifiers were hybrids, one channel per chip, mounted on cards connected with as short leads as was feasible to the anode wire connection traces on the anode printed circuit boards. The 16 preamplified signals were then shipped on short co-axial cables to amplifier-shaper-discriminator (ASD) cards. These were of the same basic design as the circuits used in several tracking systems¹³ for the CDF detector with two minor modifications: a variable resistor was added so that the gain of each channel could be trimmed by $\sim 30\%$ to establish system uniformity, and the range over which the discriminator thresholds could be varied was increased to the appropriate signal size for capture of a TR photon. This was determined in the source tests to be discussed in the next section to be 430 mV corresponding to capture of a 4 keV x-ray. With this threshold, energetic δ -rays along the charged particle track were found to yield a false signal about 10% of the time. The 16 discriminated signals from each detector plane were combined in a logical OR by a LeCroy 4564 and these were in turn input to a LeCroy 4448 gated latch. The latch gate signal was generated by a small scintillation counter placed upstream of the array and was made long enough to allow for the maximum chamber drift time of 120 ns. This latched plane hit information was stored as part of the event record for every trigger recorded. Use of a "pole-zero" filter for signal shaping on the ASD card resulted in a FWHM of the output pulse for an Fe^{55} source pulse incident of 26 ns. In principle, all electronically separable clusters i. e., those separated by more than the 26 ns, could have been counted in a special purpose processor for use in selection of events by particle type. E715⁹ used a processor like this in their electron selection. In practice, since the average number of TR photons detected per plane was expected to be $\sim .45$ for the upstream of the two chamber planes and $\sim .2$ for the downstream according to the simulations, the decision

to count only one cluster per plane in a commercially available latch was not expected to decrease the resolution in particle selection significantly.

Prototype Source Testing

A prototype chamber was constructed and tested with Xe-CO₂ 80%/20% and xenon bubbled through methylal at 0°C, which results in a mixture that is $\approx 90\%$ xenon. Since the first gas mixture showed much lower gain, and raising the voltage to improve this caused the chamber to arc down, it was quickly abandoned as a useful gas mix. The xenon-methylal mix was proportional over a large range and was stable. Because the chamber gain showed a strong dependence on the methylal temperature, the xenon was bubbled through a methylal reservoir housed in a freezer unit which maintained the desired temperature to several tenths of a degree during data taking. Three sources were used in testing, Ru₁₀₆ to model minimum ionizing tracks, Fe₅₅, and a dial-up x-ray source which emits the k_{α} x-rays from Cu, Rb, Mo, and Ag¹⁴. Thus the chamber was exposed to x-rays which bracketed the expected TR spectrum from the radiators as shown along the horizontal axis of Figure 3. The chamber voltage was set to put the Ag signal close to amplifier saturation to give the maximum discrimination between the signal due to a single minimum ionizing track passing through the cell and capture of a TR photon while maintaining linearity throughout the TR spectrum.

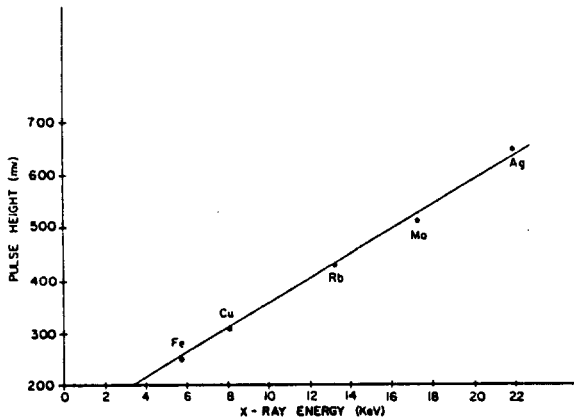


Fig 6. Most probable pulse height in millivolts vs x-ray energy for the sources used in prototype testing.

In carrying out the source tests, the ASD analog output was divided into two equal signals and sent to a discriminator set to a low threshold, well below the peak due to a single minimum ionizing particle, for self-triggering and to the input of a 2249 LeCroy ADC. This same circuit was used to monitor an on-board Fe₅₅ source during the data taking run for calibration purposes to maintain gain uniformity chamber by chamber. The results of the source tests are shown in Figure 6, which shows the most probable pulse height in millivolts vs x-ray energy. The chamber is seen to be operating in the proportional region. The signal sizes are one-half the size of those which go to the discriminator on the ASD card because of the double termination. To set the threshold at 4 keV, this discriminator threshold was therefore set to 430 mV (two times 215 mV which is the signal size corresponding to 4 keV in Fig. 5) and the digital ASD output signals were sent to a 4448 latch

gated with the same self-trigger. The efficiency for being above this threshold for all five x-ray sources was $\sim 83\%$ due to a low energy tail which can be explained as partly due to escape of some photo-electrons from the chamber volume and partly due to charge sharing by two wires from adjacent sets. That the efficiency is flat is not too surprising, since the width of the peak as well as the position of the peak grows with energy. The efficiency for detection of the Ru₁₀₆ signals was considerably smaller, 8.2%. These values were then used in setting operating conditions for data taking (Fe₅₅ gain and discriminator threshold) and to estimate the system performance.

System Performance

A histogram of the number of TRD planes/event that fired for events where the beam track was not identified by the DISC as a kaon is shown for a typical positive beam run in Figure 7. The proton peak averages to 3.8 planes/event and the pion peak to 16.2, where events with less than or equal to 7 planes/event are called protons and events with greater than or equal to 10 and less than or equal to 30 planes/event are called pions. The probability per event for each of the 48 planes in the detector to fire for passage of a minimum ionizing particle in the absence of TR is then determined using the protons, since they are well below the TR threshold. Typically, this probability is around 10%. These probabilities could then be used to simulate the minimum ionizing component of the system response to pions in the Monte Carlo program described below.

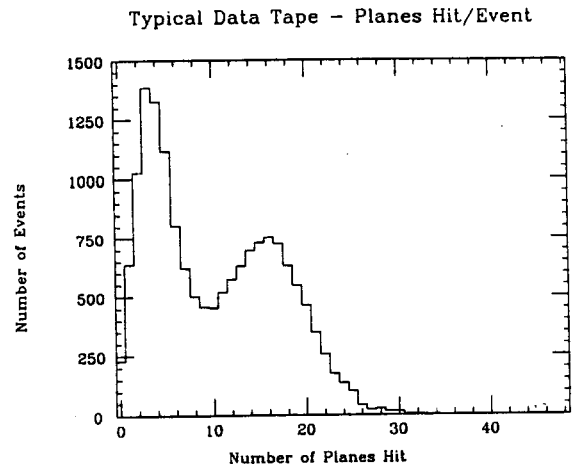


Fig 7. Number of TRD planes per event that registered a hit for events where the beam particle was not identified as a kaon by the DISC Cerenkov counter on a typical data tape.

The average number of photons radiated above 4 keV by the 200 12.7 μ m foil stack and absorbed in the 2-plane chamber with a 90% xenon fill obtained by integrating the curve in Figure 3 is 1.116. Multiplying by the 83% efficiency for the signal to be above the ASD discriminator threshold, the average number of photons per radiator-chamber set becomes .926. For each of 10,000 Monte Carlo events, a Poisson distribution with this average number was sampled 24 times to get the number of detected x-rays per assembly. The energy distribution for the detected x-rays calculated using the Maryland program was used to generate the expected capture point distribution for the 2-plane assembly. Only one x-ray per plane could be counted by the triggering electronics so this was included in the modeling. For each plane, if no TR photon was

detected, the possibility of a hit due to an energetic delta ray was put in with the probability calculated for that plane using the proton data. Again, only one "x-ray" could be counted per plane. Figure 8 compares the plane hit probabilities per event for pion data (solid line) to the Monte Carlo estimates (dashed line). The Monte Carlo is seen to overestimate the front plane responses and to underestimate the back plane responses for most of the system, making the comparisons better for a two-plane assembly. The TR response of 20 of the 24 assemblies agrees to better than 10% with the Monte Carlo estimates.

Plane by Plane Comparison of Data and Monte Carlo

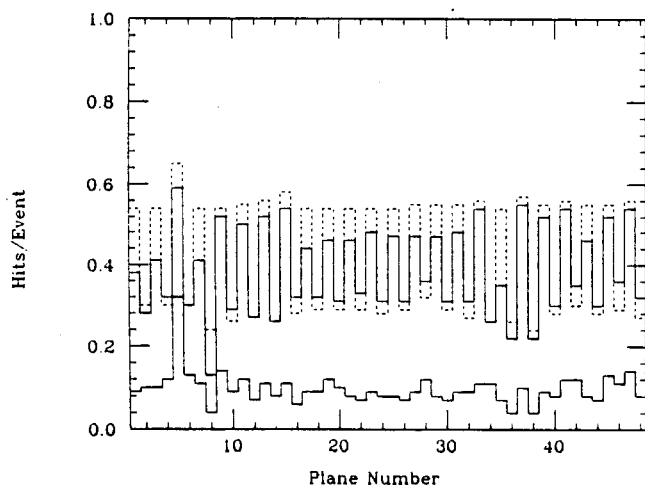


Fig 8. Hit probability per plane of the TRD per event for protons (lower solid line) and pions (upper solid line). The Monte Carlo prediction for the pion hit probability per plane per event is shown as the dashed line.

The real test of the detector, of course, is how well it identifies the beam species. To study this, pairs of tapes were taken where the DISC pressure was set to give a positive tag for either protons or pions. The TRD hit number distributions for identified protons and pions from one of these pairs of tapes are shown in Figures 9 and 10.

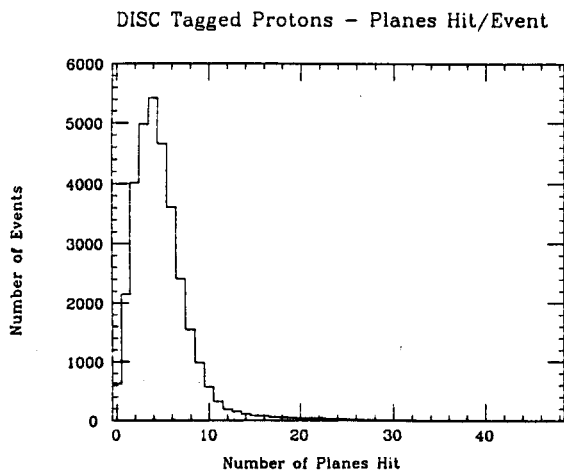


Fig 9. Number of TRD planes per event that registered hits for a sample of DISC tagged protons.

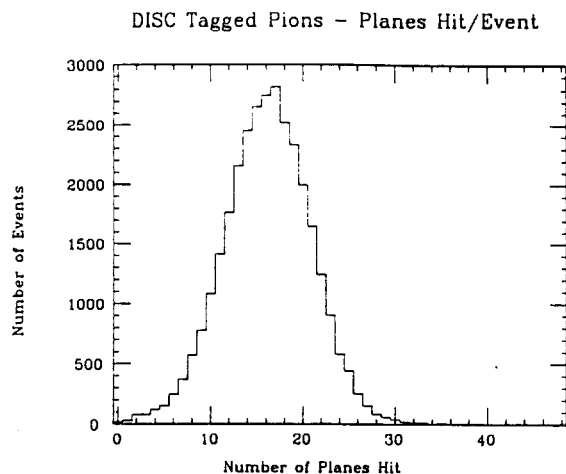


Fig.10 Number of TRD planes per event that registered hits for a sample of DISC tagged pions.

Similar distributions from another set of runs taken somewhat later in the data taking period were subjected to varying cuts to study the efficiency for detecting each particle type versus the contamination by the other. Despite a trigger veto to remove events in which two beam particles traversed the TRD within the latch gate time, about 10% of the events had two tracks going through the TRD within the gate. These events were removed in the histograms shown and in the analysis by cutting events with excess hits in the two stations of proportional wire chambers used in tracking the beam particles which were downstream of the TRD's. The beam composition assumed in making the following table was 59% pions and 35% protons, the remaining 6% being kaons.

The results shown are preliminary. Analysis of these data is still in progress. More details on the performance of the detector will be presented in Ref. [15].

TRD Performance

Pions

# of TRD Planes That Fired	Pion Efficiency	Proton Contamination
≥ 8	.946	3.0%
≥ 10	.868	2.0%
≥ 12	.733	1.9%

Protons

# of TRD Planes That Fired	Proton Efficiency	Pion Contamination
≤ 6	.865	3.5%
≤ 7	.924	5.7%
≤ 8	.951	9.7%

Acknowledgments

All components of the TRD were constructed at Fermilab in the Research Facilities Department, Technical Support Section, and Physics Department Electronics Shops. We wish to express our thanks for their effort and expertise. Also, we wish to acknowledge the assistance of our E769 colleagues in installing the TRD and keeping it operational during the run.

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